Designing Vehicle CO_2 Emission Standards
Uniform vs. Weight-Based Standards

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Abstract

In this paper we will analyze different approaches to implementing vehicle CO_2 emission standards. By means of a straightforward microeconomic model w*e assess the relative favourability of reference parameter based vehicle emissions standards – in particular weight-based standards – compared to uniform standards. In case of heterogeneous manufacturers, vehicle specific emission targets that are set according to a certain reference parameter can improve the cost efficiency of the regulation by smoothing the marginal abatement costs, but they distort the allocation decision between different available abatement options. None of the analyzed approaches shows a general dominance over the others; however, for each set of circumstances the optimal design of the standard can be theoretically determined. First results emphasize the crucial impact of the market structure (i.e. market concentration rates, cost structures, and particularly the heterogeneity of the vehicle manufacturers) on the relative favourability.*

The EU (linear weight-based standards) and the US (presumably S-shaped footprint-based standards) have made different choices with respect to the reference parameter used for their fuel economy regulations. Our results suggest that using vehicle weight as reference parameter will lead to greater distortions in the allocation decision between different abatement options. Adjusting the reference parameter (e.g. weight reduction, downsizing) in order to abate CO_2-emissions will be devaluated by linking the specific emission target to the level of the reference parameter. This problem seems to be of greater importance in the case of weight based standards, as a footprint-based regulation is less vulnerable to adjustments in the design of the vehicles in order to boost the baseline – due to technical reasons and for lack of consumer acceptance. Weight-based standards will presumably result in a suboptimal fleet structure; the vehicles are heavier than optimal.

Please note that the current preliminary version of the paper is a very early draft that will undergo expansion and several revisions before the conference is held! An application of the theoretical results to the legislation actually proposed in the EU and the US will also follow!

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1 Introduction

Transport accounts for one quarter and almost one third of the CO2 emissions in the EU and the USA respectively, whereof the major part derives from road transport. In view of its major and still rising share of aggregate greenhouse gas (GHG) emissions, transportation has come under increasing political pressure to be integrated into a future climate policy regime. The achievement of the 2020 targets of the EU (-20%) and Germany (at least -30%) as well as the commitment to climate protection of the new US administration render a contribution of the transport sector inevitable. In order to achieve CO2 emission reductions in the transport sector four levers of action are generally available: reduction of the general transport demand (in terms of pkm and tkm), modal shift towards more environmentally benign modes, improvement of the vehicles energy efficiency, and a reduction of the carbon intensity of fuels. Efficiency improvements to existing internal combustion engine vehicles offer by far the greatest emission reduction potential; a significant share of this potential even comes at net negative cost. Thus, the European Commission has proposed legislation limiting the specific emissions of passenger cars to 130 grams CO2 per kilometre by the year 2012.[1] Also in the US, the Congress has passed legislation that will tighten the federal fuel economy standards for light trucks and passenger cars;[2] California and some other states are heading for even stricter regulations. Besides these major automobile markets, further countries have fuel economy regulations in place or are planning to implement them, e.g. Japan, China, South Korea or Taiwan.

Vehicle emission standards, as well as the very closely related fuel economy standards, strive for a reduction of GHG emissions and for a gradual reduction of oil dependency by means of mandatory carbon/fuel efficiency improvements. The necessity for mandatory vehicle emission standards is claimed to be the consequence of a failure in inducing intended behavioural changes through the transmission of price signals. When purchasing durable energy consuming goods, consumers are assumed to act myopic, to lack sufficient information for rational decision-making, or to rely on simple decision heuristics due to limited cognitive capabilities [see e.g. Turrentine/Kurani (2007), Kempton/Layne (1994), Moxnes (2004), Antonides/Wunderink (2001), Kooreman (1995)]. Consequently, they do not take future fuel costs appropriately into account when choosing a new car In addition, technology spill-overs, uncertainty about future fuel and carbon costs as well as lacking credibility of climate policy may support procrastination of investments in fuel efficiency technologies on the part of the automobile manufacturers.

There is a broad literature examining the efficiency and effectiveness of fuel economy standards, basically focusing on the Corporate Average Fuel Economy (CAFE) regulations in the US, which were already introduced in 1975 in the wake of the 1973 oil crisis [e.g. Parry/Walls/Harrington (2007), Fischer/Harrington/Parry (2007), Kleit (2004), Portney/Parry/Gruenspecht/Harrington (2003), Greene (1998)]. Their appraisal and the answer to the question whether vehicle emission/fuel economy standards or financial incentives are preferable is ambiguous. Ellerman/Jacoby/Zimmerman (2006) have examined possible approaches to integrate the CAFE standards with a cap-and-trade system for GHG, which would connect fuel economy regulations with financial incentives schemes. Yet, the question how vehicle emission standards should be designed in detail has been widely disregarded so far.

When it comes to the implementation of vehicle emission standards there prevail two main options for their design:

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[1] Some amendments to the original proposal have been negotiated that weaken its effectiveness.

[2] In average all passenger vehicles have to achieve 35 MPG by the year 2020.

- Uniform standards: Each manufacturer or even each vehicle has to comply with the same standard, defined in terms of g CO_2 per vehicle kilometer (vkm) or MPG (e.g. CAFE)
- Reference parameter based standards: The manufacturer specific or vehicle specific standards are defined with respect to a certain reference parameter (e.g. EU standards, revised CAFE standards). By means of using such a parameter differences in the marginal abatement costs should be taken into account.

In a heterogeneous vehicle market uniform standards are likely to cause excessive abatement costs as it is more costly to reach an identical emission standard for manufacturers of heavy, high-performance cars than for manufacturers of smaller cars. On the other hand, reference parameter based standards may distort the choice between different abatement options. In this paper we will analyze the implications of either approach on the cost efficiency of the regulation as well as market structures that support either of these approaches.

2 Fuel Economy Regulations around the World

European Union

The European Commission has announced its proposal to reduce the CO_2 emissions from passenger cars by means of emission performance standards as a part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. The Commission’s proposal relies on performance-based standards and adds some flexibility by allowing offsetting across different manufacturers.

The target value aimed at with the regulation is 130 g CO_2 per km as average for the entire fleet of new vehicles sold in the EU. Vehicle weight has been chosen to be the reference parameter. Vehicles weighting exactly the average weight of newly sold cars (1289 kg in 2006) are allowed to emit 130 g CO_2 per km, for each additional/fewer kg the assigned specific emission limit increases/decreases. By defining manufacturer specific emission targets depending on deviations of its vehicles’ weight from the fleet-wide average weight, it is ensured that the emission target can be achieved even if the average weight of the fleet increases. The increment of the specific standard per additional kg of vehicle weight is constant, i.e. the limit value curve is linear. The slope of the limit value curve is 4.57 g CO_2/km per 100 kg vehicle weight. Hence, the slope of the limit value curve is lower than the change in CO_2 emissions physically associated to a variation of vehicle weight; simulations of weight induced CO_2 emission changes showed – assuming adjusted rear axle transmission – a round about twice as strong impact.[3]

Manufacturers exceeding the limit have to pay penalties for each gram by which the average emissions of their sold cars exceed the target, multiplied by the number of cars sold. In order to avoid paying the penalty, manufacturers whose emissions exceed their target can group together with manufacturers below their specific target to form a pool that can jointly comply with the regulation. Of course, the more carbon-efficient manufacturers that offset the excess emissions of their pooling partners will demand for a (financial) compensation.

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[3] See Helms, H. / Lambrecht, U. (2006), Eberle, R. (2000). There exist further studies, which show a significant spreading in the estimates on the correlation between vehicle weight and CO_2-emissions/fuel consumption. It has to be noted here, that a regression of the observed correlation between vehicle weight and specific CO_2-emissions is not feasible as heavier cars often also comprise stronger engines and other features that increase the specific fuel consumption.

USA

In 1975, the USA were the first to introduce fuel economy regulations in the wake of the 1973 oil crisis. However, the CAFE standards rather aimed at reducing the oil dependency of the USA than at cutting the emission of greenhouse gases. The vehicle fleet is divided into two classes, light trucks and passenger cars, each having its own standard. The car standard is stricter than the light truck standard; a further differentiation within these classes is not made. Offsetting is allowed within a manufacturer's fleet for the same vehicle segment, but not between cars and light trucks nor between different manufacturers. To enhance the flexibility of the scheme surplus credits generated for doing better than the standard can be banked for up to three years. Manufacturers who do not comply with the standards have to pay a fine of 5.50 US-$ per vehicle for each 0.1 MPG (miles per gallon) that their actual fuel economy falls short of the standards.

The CAFE standards proved successful in improving the fuel economy of both passenger cars and light trucks.[4] Fuel economy improved (almost) steadily until the year 1988, although fuel prices started falling in 1982. Since then the fuel economy in both segments has remained almost constant until 2001, afterwards rising again and reaching new peaks in 2008 with 31.0 MPG and 23.4 MPG for cars and light trucks respectively. However, despite the constancy of fuel economy within each segment, the combined fuel economy of the entire fleet decreased in the same period, from 26.2 MPG in 1987 to 24.5 MPG in 2001. This was due to shifts in the fleet structure from cars to light trucks. The share of light trucks increased from less than 10% of all new vehicles sold in 1979 to significantly more than the half in 2004 and 2005. Though this shift cannot be entirely explained with the introduction of the CAFE regulation as consumer preferences have also changed over time, the differentiation in weaker standards for light trucks and tighter standards for cars had certainly an influence on the observed development. This underlines with evidence the importance of a standard design, which does not provide for adverse incentives regarding vehicle design and fleet structure.

From the year 2011 revised CAFE standards will come into force.[5] By the year 2020 the entire light duty vehicle fleet has to achieve an average MPG value of 35. The standards for passenger cars as well as those for light trucks – i.e. standards for both segments will remain differentiated – depend on their footprint, deploying a continuous S-shaped calculation formula. The limit value curve will be fixed for a certain compliance period; thus, changes in the average footprint are not succeeded by immediate changes in the limit value curve. The precise details of the reformed CAFE regulation are still to be announced.

Japan

Japan has introduced fuel economy regulations, differentiated between gasoline and diesel vehicles, that are based on the top-runner approach; the regulation also uses weight as reference parameter for assigning the vehicles to eight classes with own standards. Averaging across different weight classes within a manufacturer's fleet is allowed only on a two-for-one basis, i.e. credits earned by vehicles better than the standard in one weight class are discounted by 50% when used for offsetting emissions exceeding the standard in another weight class. Thereby some flexibility is withheld from the market. The fuel economy target for each weight class is determined by the top-runner.

The regulator selects a representative "best-in-class" vehicle as top-runner; vehicles with unusual, very expensive technology and with only few sales are exempted from being the top-runner. Otherwise a very carbon-efficient niche vehicle could become the standard setting top-runner for the mass of vehicles, which are not seriously comparable to the top-runner.

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[4] See NHTSA (2008).

[5] Manufacturers of light trucks can be subject to the new standards already from 2008 on a voluntary basis.

The relatively wide range of weight classes, which implies significant differences in fuel economy improvement requirements and marginal fuel reduction costs, facilitates “edge effects”. For vehicles at the top of the weight range within a certain weight class there exist incentives to increase there weight by that amount, which shifts it to the next higher weight class in order to boost the emission limit of that vehicle. For manufacturers of vehicles at the bottom of a weight class it is rational not to further reduce the weight as the thereby achieved emission reduction will presumably be outweighed by the subsequent tightening of the standard due to the shift into a lower weight class.

The penalties for manufacturers, which do not comply with the standards, are relatively low. Enforcement will supposedly be achieved mainly through pressure from the public and the government, and the companies’ desire to avoid public embarrassment. Whether this punishment approach would be feasible in another cultural framework, e.g. Europe or the USA, is questionable.

Further Countries

Besides, these three major automobile markets further countries have fuel economy regulations in place. For instance, China also relies on discrete weight-based standards, i.e. specific targets for several defined weight classes. The Chinese regulation does not allow averaging within a manufacturer’s fleet; each model is required to meet the standard for its class. California strives for own CO_2 regulations for automobiles. The proposed legislation divides the fleet in two classes, cars as well as small light duty trucks and bigger light duty trucks; a uniform form standard is applied for each of the classes.

Taiwan and South Korea employ neither weight nor the footprint as reference parameter, but the engine size instead. While the Taiwanese regulation sets own standards for several engine size classes, South Korea distinguishes only between two categories of engine displacement.

In this early version of the paper we will focus on uniform standards and weight-based standards compliant with the proposal of the EU Commission. Subsequently, we will examine further alternative designs of weight-based standards. At the present moment only the analysis of standards based on past values of the vehicle weight has been finished; further designs such as the introduction of tradable credits will follow soon.

3 Basic Model

The basic model is essentially based on two functions: the CO_2 emission function and the reduction cost function. For simplicity reasons and to focus on the impact of using weight as reference parameter, we describe the vehicles by only two attributes: their weight (x_w) and “others” (x_o), which comprises all remaining emission-relevant attributes (e.g. combustion technology, air drag, engine displacement, etc.).

The independent variables are the reduction efforts of the vehicle manufacturers. Each manufacturer can decide to what extent it reduces its average vehicle weight and its average value of “others”. The reduction efforts of a manufacturer i ($\varphi_{i,w}^t$ and $\varphi_{i,o}^t$) are expressed as the relative change in weight and “others” between the target period t and starting period 0:

$$\varphi_{i,w}^t = \frac{x_{i,w}^0 - x_{i,w}^t}{x_{i,w}^0} \text{ and } \varphi_{i,o}^t = \frac{x_{i,o}^0 - x_{i,o}^t}{x_{i,o}^0}$$

We assume that the manufacturers can decide on $\varphi_{i,w}^t$ and $\varphi_{i,o}^t$ on a continuous scale.

CO_2-Emission Function

The emissions of a manufacturer i are determined by the weight of its vehicles and all remaining emission-relevant vehicle attributes, condensed in the parameter “others”.

Emissions per vkm of manufacturer i in period t:

$$E_i^t(x_{i,w}^t, x_{i,o}^t) = E_i^t\left(\left(x_{i,w}^0 - \varphi_{i,w}^t \cdot x_{i,w}^0\right), \left(x_{i,o}^0 - \varphi_{i,o}^t \cdot x_{i,o}^0\right)\right)$$

In the following we will assume that the marginal emission reduction costs via weight reduction are independent of the value of “others” and vice versa. Of course, in reality there are certain dependencies between different abatement measures; however, for the purpose of this paper this is of minor importance as we try to derive some general insights on the design of fuel economy standards rather than giving a realistic, detailed cost analysis. We further assume a constant marginal emission reduction due to a reduction of weight and “others” by one unit (e.g. kg):

$$\frac{\partial E_i^t}{\partial x_w^t} = \delta_w \approx const \forall i = 1, \ldots, n \text{ and } \frac{\partial E_i^t}{\partial x_o^t} = \delta_o \approx const \forall i = 1, \ldots, n$$

The derivations of a manufacturer’s emissions with respect to $\varphi_{i,w}^t$ and $\varphi_{i,o}^t$ are given by:

$$\frac{\partial E_i^t}{\partial \varphi_{i,w}^t} = -x_{i,w}^0 \cdot \partial E_i^{t}{}'\left(x_{i,w}^0 - \varphi_{i,w}^t \cdot x_{i,w}^0\right) = -x_{i,w}^0 \cdot \delta_w,$$

$$\frac{\partial E_i^t}{\partial \varphi_{i,o}^t} = -x_{i,o}^0 \cdot \partial E_i^{t}{}'\left(x_{i,o}^0 - \varphi_{i,o}^t \cdot x_{i,o}^0\right) = -x_{i,o}^0 \cdot \delta_o;$$

The average emissions (g CO_2 per vkm) of the entire fleet of the economy are then given by

$$E^t = \sum_{i=1}^{n} \left(E_i^t(x_{i,w}^t, x_{i,o}^t) \cdot MS_i\right)$$

with MS_i being the market share of manufacturer i: $\sum_{i=1}^{n} MS_i = 1$

The market shares of the manufacturers are assumed to be constant over time.

Reduction Cost Function

The reduction costs of a manufacturer depend on the relative as well as the absolute reduction in the parameters weight and “others”. The absolute and the relative reduction are of course not independent variables, but linked via the initial values (values in period t=0) of weight and “others”. Thus, the manufacturer decides on the relative reduction of weight/”others” ($\varphi_{i,w}^t$ and $\varphi_{i,o}^t$), which implies a certain absolute reduction depending on the initial values. We define the reduction cost function to be constituted by the sum of costs for weight reduction and reduction of “others”, i.e. the chosen function implies that the costs for using one reduction option are independent from the other option.

Reduction costs per vehicle of manufacturer i: $RC_i^t(\varphi_{i,w}^t, \varphi_{i,o}^t)$

$$RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)=\beta_w\cdot\varphi_{i,w}^t\cdot\left(x_{i,w}^0-x_{i,w}^t\right)+\beta_o\cdot\varphi_{i,o}^t\cdot\left(x_{i,o}^0-x_{i,o}^t\right)=\beta_w\cdot\left(\varphi_{i,w}^t\right)^2\cdot x_{i,w}^0+\beta_o\cdot\left(\varphi_{i,o}^t\right)^2\cdot x_{i,o}^0$$

We assume the reduction cost function to be convex. It seems reasonable that the reduction costs increase disproportionally as more sophisticated technologies have to be employed for higher reduction efforts. Besides technology costs, the reduction costs also implicitly contain components such as reduced attainable retail prices due to modified vehicle attributes.

$$MRC_{i,w}^t=\frac{\partial RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)}{\partial\varphi_{i,w}^t}>0 \text{ and } \frac{\partial MRC_{i,w}^t}{\partial\varphi_{i,w}^t}=\frac{\partial^2 RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)}{\partial\left(\varphi_{i,w}^t\right)^2}>0;$$

$$MRC_{i,o}^t=\frac{\partial RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)}{\partial\varphi_{i,o}^t}>0 \text{ and } \frac{\partial MRC_{i,o}^t}{\partial\varphi_{i,o}^t}=\frac{\partial^2 RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)}{\partial\left(\varphi_{i,o}^t\right)^2}>0$$

The average reductions costs of the entire fleet of the economy are given by $RC^t=\sum_{i=1}^{n}\left(RC_i^t(\varphi_{i,w}^t,\varphi_{i,o}^t)\cdot MS_i\right)$

Definition of the Standard

The regulator aims at reaching a certain (relative) emission target, in terms of average CO_2-emissions per vkm, in period t.

Targeted average emissions for the entire vehicle fleet in period t: $\overline{E}^t=\sum_{i=1}^{n}\left(E_i^t\cdot MS_i\right)$

The two – here considered – approaches to reach the target are either uniform standards, which stipulate an identical target for all manufacturers, or weight-based standards. Weight-based standards should take account of differing initial weights between manufacturers and therefore differing marginal reduction costs.

Uniform standard: $\overset{u}{E_i^t}=\overline{E}^t\,\forall i=1,\ldots,n$

Each manufacturer i has to comply in t with the same emission standard $\overline{E}^t$.

Weight-based standard: $\overset{wb}{E_i^t}=\overline{E}^t+\alpha\cdot\left(x_{i,w}^t-\sum_{i=1}^{n}\left(x_{i,w}^t\cdot MS_i\right)\right)\forall i=1,\ldots,n$

The specific emission standard for manufacturer i to be reached in period t depends on the average weight of its vehicles and also on the average weight of the other manufacturers' vehicles. In order to assure achieving the economy-wide emission target, the manufacturer specific target is determined by the deviation of manufacturer i's vehicle weight from the economy-wide fleet average. There is also a regulation design conceivable that links manufacturer specific targets only to their absolute vehicle weight, without considering the economy-wide average. However, such standards would not guarantee achieving the environmental target, i.e. $\overline{E}^t$.

The impact of weight differences on the manufacturer specific emission targets is determined by the parameter α. The greater α, the greater is the differentiation of manufacturer specific emission targets.

Finally it has to be noted that we do not take account of the specific fleet structure of any manufacturer. We assume that the emission function as well as the reduction cost function of a manufacturer can be defined as a function of its average weight and its average value of "others". One could also interpret i as being a vehicle type; then the weight-based standards would not represent manufacturer specific targets based on the average weight of the manufacturer's fleet, but vehicle type specific targets. Vehicle type specific targets would not allow for averaging within a manufacturer's fleet. Further we do not consider changes of the market shares due to modified vehicle attributes. Consumer reactions are merely implicitly considered as being part of the reduction costs in the form of changes in the attainable market price due to altered vehicle characteristics.

Heterogeneity of Manufacturers

Besides the emission standard being subject to, the manufacturer specific abatement costs and consequently also the aggregate abatement costs depend on a multitude of influencing variables. Striving for an identical target may yield considerable disparities in the MAC of different manufacturers. Thus, differentiating the manufacturer specific emission reduction targets with view to their individual marginal abatement costs is the main argument brought forward in favor of weight-based standards. In general, heterogeneous manufacturers could be different in their

i) initial values of weight and "others"
ii) reduction cost functions
iii) emission functions
iv) their market shares

We focus mainly on i), i.e. on different initial values of weight and "others", because the differing initial emission resulting from differences in the vehicles' weight are the stated justification for the introduction of weight-based standards. We further allow for different market shares, but for simplicity we assume identical reduction cost functions and identical emission functions, i.e. β_w, β_o, δ_w, δ_o are equal for all manufacturers.

In order to incorporate heterogeneity we introduce a multiplier that represents differences in the initial values of weight and "others":

$$\phi_{i,w} = \frac{x_{i,w}^0}{x_w^0} \Rightarrow x_{i,w}^0 = \phi_{i,w} \cdot x_w^0 \text{ with } x_w^0 = \sum_{i=1}^{n} (x_{i,w}^0 \cdot MS_i) \text{ and } \sum_{i=1}^{n} (\phi_{i,w} \cdot MS_i) = 1$$

$$\phi_{i,o} = \frac{x_{i,o}^0}{x_o^0} \Rightarrow x_{i,o}^0 = \phi_{i,o} \cdot x_o^0 \text{ with } x_o^0 = \sum_{i=1}^{n} (x_{i,o}^0 \cdot MS_i) \text{ and } \sum_{i=1}^{n} (\phi_{i,o} \cdot MS_i) = 1$$

4 Social Economic Optimum

Before we examine the efficiency properties of uniform and weight-based standards, we first define the reference case for all regulatory approach, i.e. the social economic optimum. In the optimum the reduction costs for reaching the targeted emission standard $\overline{E}^t$ are to be minimized:

$$RC^t = \min_{\varphi_{i,w}^t, \varphi_{i,o}^t} \sum_{i=1}^{n} \left(RC_i^t(\varphi_{i,w}^t, \varphi_{i,o}^t) \cdot MS_i \right)$$

$$\text{s.t. } \sum_{i=1}^{n} \left(E_i^t(x_{i,w}^t, x_{i,o}^t) \cdot MS_i \right) = \overline{E}^t$$

In the optimum it has to hold:

$$\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}=\frac{MRC_{j,w}^{t}\cdot\frac{1}{x_{j,w}^{0}}}{\delta_{w}}\forall i,j=1,\ldots,n$$

$$\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,o}^{0}}}{\delta_{o}}=\frac{MRC_{j,o}^{t}\cdot\frac{1}{x_{j,o}^{0}}}{\delta_{o}}\forall i,j=1,\ldots,n$$

$$\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}=\frac{MRC_{i,o}^{t}\cdot\frac{1}{x_{i,o}^{0}}}{\delta_{o}}\forall i=1,\cdots,n$$

We can define $\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}$ and $\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,o}^{0}}}{\delta_{o}}$ as the marginal abatement costs (MAC) for emission abatement by means of weight reduction and reduction of “others” respectively.

$$\frac{MRC_{i,w}^{t}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}=MAC_{i,w}^{t} \text{ and } \frac{MRC_{i,o}^{t}\cdot\frac{1}{x_{i,o}^{0}}}{\delta_{o}}=MAC_{i,o}^{t}$$

We then get the well-known conditions for a social optimum: Equality of the MAC across all abatement options, here reduction of weight and “others”, as well as equal MAC across all manufacturers.

$$MAC_{i,w}^{t}=MAC_{j,w}^{t}\forall i,j=1,\ldots,n$$

$$MAC_{i,o}^{t}=MAC_{j,o}^{t}\forall i,j=1,\ldots,n$$

$$MAC_{i,w}^{t}=MAC_{i,o}^{t}\forall i=1,\ldots,n$$

Using the above definition of the RC function, the marginal abatement costs are given by:

$$MAC_{i,w}^{t}=\frac{2\cdot\beta_{w}\cdot\varphi_{i,w}^{t}\cdot x_{i,w}^{0}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}=\frac{2\cdot\beta_{w}\cdot\left(\frac{ER_{i,w}^{t}\cdot\frac{1}{\delta_{w}}}{x_{i,w}^{0}}\cdot\right)\cdot x_{i,w}^{0}\cdot\frac{1}{x_{i,w}^{0}}}{\delta_{w}}=\frac{2\cdot\beta_{w}}{(\delta_{w})^{2}\cdot x_{i,w}^{0}}\cdot ER_{i,w}^{t}$$

with $ER_{i,w}^{t}=\left(x_{i,w}^{0}-x_{i,w}^{t}\right)\cdot\delta_{w}$ being the emission reduction (in terms of g CO_2 per vkm) achieved by manufacturer i between period 0 and period t by means of weight reduction

Analogue, we get for the MAC of emission abatement by means of reducing “others”

$$MAC_{i,o}^{t} = \frac{2 \cdot \beta_o}{(\delta_o)^2 \cdot x_{i,o}^{0}} \cdot ER_{i,o}^{t}$$

In the following we will focus on the direct emission reduction rather than on relative reductions in weight and "others" ($\varphi_{i,w}^{t}$ and $\varphi_{i,o}^{t}$).

$$ER_i^t = ER_{i,w}^t + ER_{i,o}^t = E_i^0 - E_i^t$$

The emission target $\overline{E}^t$ can be translated into the required emission reduction:

$$\overline{ER}^t = \sum_{i=1}^{n} \left(E_i^0 (x_{i,w}^0, x_{i,o}^0) \cdot MS_i \right) - \overline{E}^t$$

In the following we will normalize the initial values of weight and "others" by setting $x_w^0 = 1$ and $x_o^0 = 1$ in order to further simplify the equations; consequently, the values for β_w, β_o, δ_w, δ_o have to be adjusted accordingly.

The abatement costs of a single manufacturer are then given by:

$$AC_i = \int_0^{ER_{i,w}^t} \frac{2 \cdot \beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot ER_{i,w}^t + \int_0^{ER_{i,o}^t} \frac{2 \cdot \beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot ER_{i,o}^t$$

The optimization problem can be reformulated to:

$$\overset{opt}{AC} = \min_{ER_{i,w}^t, ER_{i,o}^t} \sum_i \left(\left(\int_0^{ER_{i,w}^t} \frac{2 \cdot \beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot ER_{i,w}^t + \int_0^{ER_{i,o}^t} \frac{2 \cdot \beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot ER_{i,o}^t \right) \cdot MS_i \right)$$

s.t. $\overline{ER}^t = \sum_{i=1}^{n} \left(\left(ER_{i,w}^t + ER_{i,o}^t \right) \cdot MS_i \right)$

Of course, the first order conditions remain the same, i.e. i) equality of the MAC for weight reduction across all manufacturers, ii) equality of the MAC for reduction of "others" across all manufacturers, iii) equality of MAC for weight reduction and reduction of "others". The optimal allocation of emission reductions efforts for each manufacturer and their relation across manufacturers is now explicitly dependent on their initial values of weight and "others":

$$\frac{ER_{i,w}^t}{\phi_{i,w}} = \frac{ER_{j,w}^t}{\phi_{j,w}} \Rightarrow \frac{ER_{i,w}^t}{ER_{j,w}^t} = \frac{\phi_{i,w}}{\phi_{j,w}} \Rightarrow ER_{j,w}^t = ER_{i,w}^t \cdot \frac{\phi_{j,w}}{\phi_{i,w}} \forall i, j = 1, \ldots, n$$

$$\frac{ER_{i,o}^t}{\phi_{i,o}} = \frac{ER_{j,o}^t}{\phi_{j,o}} \Rightarrow \frac{ER_{i,o}^t}{ER_{j,o}^t} = \frac{\phi_{i,o}}{\phi_{j,o}} \Rightarrow ER_{j,o}^t = ER_{i,o}^t \cdot \frac{\phi_{j,o}}{\phi_{i,o}} \forall i, j = 1, \ldots, n$$

$$\frac{\beta_w \cdot ER_{i,w}^t}{\left(\delta_w\right)^2 \cdot \phi_{i,w}} = \frac{\beta_o \cdot ER_{i,o}^t}{\left(\delta_o\right)^2 \cdot \phi_{i,o}} \Rightarrow ER_{i,o}^t = ER_{i,w}^t \cdot \frac{\beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o}}{\beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w}} \forall i = 1,\ldots,n$$

The higher the initial values of weight/"others", the higher is the optimal emission abatement by means of reduction of weight/"others". Comparably high initial values of the parameter imply relatively low MAC, because they allow at same costs a greater absolute reduction in the respective parameter. The allocation between reducing weight and reducing "others" is determined by i) the cost factors β_w and β_o, ii) the relation of δ_w and δ_o, and iii) the initial values of weight and "others":

ad i) The more expensive the reduction of weight or "others", the less it will be used as an abatement option.

ad ii) The greater the emission reduction per unit reduced weight/"others", the lower are the MAC and thus the more attractive is the respective abatement option.

iii) As mentioned above, high initial values of weight/"others" imply lower MAC, i.e. the higher the initial values, the more important is the respective abatement option.

Using these optimum conditions and the side condition $\overline{ER}^t = \sum_{i=1}^{n}\left(\left(ER_{i,w}^t + ER_{i,o}^t\right)\cdot MS_i\right)$, we can determine the optimum values for $ER_{i,w}^t$, $ER_{i,o}^t$, and ER_i^t :

$$ER_{i,w}^t = \overline{ER}^t \cdot \frac{\phi_{i,w}}{\sum_{j=1}^{n}\left(MS_j \cdot \left(\left(\phi_{j,w}\right) + \frac{\beta_w \cdot \left(\delta_o\right)^2}{\beta_o \cdot \left(\delta_w\right)^2} \cdot \left(\phi_{j,o}\right)\right)\right)} = \overline{ER}^t \cdot \frac{\phi_{i,w} \cdot \beta_o \cdot \left(\delta_w\right)^2}{\beta_o \cdot \left(\delta_w\right)^2 + \beta_w \cdot \left(\delta_o\right)^2} \forall i, j = 1,\ldots,n$$

$$ER_{i,o}^t = \overline{ER}^t \cdot \frac{\beta_w \cdot \left(\delta_o\right)^2}{\beta_o \cdot \left(\delta_w\right)^2} \cdot \frac{\phi_{i,o}}{\sum_{j=1}^{n}\left(MS_j \cdot \left(\left(\phi_{j,w}\right) + \frac{\beta_w \cdot \left(\delta_o\right)^2}{\beta_o \cdot \left(\delta_w\right)^2} \cdot \left(\phi_{j,o}\right)\right)\right)} = \overline{ER}^t \cdot \frac{\phi_{i,o} \cdot \beta_w \cdot \left(\delta_o\right)^2}{\beta_o \cdot \left(\delta_w\right)^2 + \beta_w \cdot \left(\delta_o\right)^2} \forall i, j = 1,\ldots,n$$

$$ER_i^t = \overline{ER}^t \cdot \frac{\beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o} + \beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w}}{\beta_w \cdot \left(\delta_o\right)^2 + \beta_o \cdot \left(\delta_w\right)^2} \forall i, j = 1,\ldots,n$$

The socially optimal emission reduction of a certain manufacturer is linear in its initial values of weight and "others". The relative importance is determined by the costs and the impact on emissions of the respective parameter.

$$\frac{ER_i^t}{ER_j^t} = \frac{\beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o} + \beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w}}{\beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{j,o} + \beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{j,w}} \forall i, j = 1,\ldots,n$$

Then the aggregate abatement costs in the minimum are given by:

$$\overset{opt}{AC} = \sum_i AC_i = \sum_i \left(\left(\int_0^{ER^t_{i,w}} \frac{\beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot ER^t_{i,w} + \int_0^{ER^t_{i,o}} \frac{\beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot ER^t_{i,o} \right) \cdot MS_i \right)$$

$$= \sum_{i=1}^{n} \left(\left(\frac{1}{2} \cdot \frac{\beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot \left(ER^t_{i,w}\right)^2 + \frac{1}{2} \cdot \frac{\beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot \left(ER^t_{i,o}\right)^2 \right) \cdot MS_i \right)$$

$$= \sum_{i=1}^{n} \left(\left(\overline{ER}^t\right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 + \beta_w \cdot (\delta_o)^2} \right) \cdot MS_i \right)$$

The economy-wide abatement costs in the optimum are determined by:

- the required emission reduction: the greater the required emission reduction, the higher are the resulting abatement costs
- the absolute level of the slopes of the marginal abatement costs curves: the steeper the marginal abatement cost functions, the higher are the abatement costs. The higher β_w and β_o and the lower δ_w and δ_o, the steeper are the slopes.
- the relation of the slopes of the MAC for weight reduction and reduction of "others": for a given absolute sum of the slopes of these MAC functions, there exists a relation that maximizes the abatement costs. This relation is given by $\frac{\beta_w \cdot (\delta_o)^2}{\beta_o \cdot (\delta_w)^2} = 1$.

  In case $\frac{\beta_w \cdot (\delta_o)^2}{\beta_o \cdot (\delta_w)^2}$ differs from this relation, the overall abatement costs can be mitigated by seizing the cheaper abatement option to a greater extent.
- The cost minimizing abatement costs are independent from the heterogeneity of the manufacturers, i.e. the variance of ϕ_w and ϕ_o. This is due to the chosen reduction cost function. In the optimum, the manufacturers will reduce emission to the exact same extent as their initial values of weight and "others" (weighted by $\frac{\beta_w}{(\delta_w)^2}$ and $\frac{\beta_o}{(\delta_o)^2}$) so that MAC are for all manufacturers will always be at the level $\overset{opt}{MAC_i} = \overline{ER}^t \cdot \frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 + \beta_w \cdot (\delta_o)^2} \forall i = 1, \ldots, n$.

5 Uniform Standard

In order to determine the compliance costs of a regulation based on uniform standards we first regard the abatement decision of an individual manufacturer before we assess the implications for a heterogeneous vehicle market. By choosing the allocation of abatement efforts between reducing weight and “others” a single manufacturer i will minimize its abatement costs subject to complying with the uniform standard, which is not dependent on any manufacturer specific attributes of the vehicles. The optimization problem it faces is analogue to the case of the social economic optimum

$$\overset{u}{AC}_i = \min_{ER^t_{i,w}, ER^t_{i,o}} \left(\int_0^{ER^t_{i,w}} MAC^t_{i,w} + \int_0^{ER^t_{i,o}} MAC^t_{i,o} \right)$$

$$= \min_{ER^t_{i,w}, ER^t_{i,o}} \left(\int_0^{ER^t_{i,w}} \frac{2 \cdot \beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot ER^t_{i,w} + \int_0^{ER^t_{i,o}} \frac{2 \cdot \beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot ER^t_{i,o} \right)$$

s.t. $ER^t_{i,w} + ER^t_{i,o} = \overset{u}{ER}^t_i = E^0_i - \overline{E}^t$

Similarly to the social optimum, in order to achieve the given required emission reduction each manufacturer will choose $ER^t_{i,w}$ and $ER^t_{i,o}$ so that the MAC of both mitigation options are equalized.

$$ER^t_{i,w} = \overset{u}{ER}^t_i \cdot \frac{\phi_{i,w} \cdot \beta_o \cdot (\delta_w)^2}{\beta_o \cdot (\delta_w)^2 \cdot \phi_{i,w} + \beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o}} \forall i, j = 1, \ldots, n$$

$$ER^t_{i,o} = \overset{u}{ER}^t_i \cdot \frac{\phi_{i,o} \cdot \beta_w \cdot (\delta_o)^2}{\beta_o \cdot (\delta_w)^2 \cdot \phi_{i,w} + \beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o}} \forall i, j = 1, \ldots, n$$

$$\Rightarrow MAC^t_{i,w} = MAC^t_{i,o} \Rightarrow \frac{\beta_w}{\phi_{i,w} \cdot (\delta_w)^2} \cdot ER^t_{i,w} = \frac{\beta_o}{\phi_{i,o} \cdot (\delta_o)^2} \cdot ER^t_{i,o} \forall i = 1, \ldots, n$$

The abatement costs of that manufacturer are then given by

$$\overset{u}{AC}_i = \sum_{i=1}^{n} \left(\left(\overset{u}{ER}^t_i \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot \phi_{i,w} + \beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o}} \right) \cdot MS_i \right)$$

However, equality of the MAC of both abatement approaches for a single manufacturer does not give us any indication whether the MAC are also equal across manufacturers. The latter depends on the manufacturer specific emission reductions to be achieved.

The required emission reduction of each manufacturer i is given by:

$$\overset{u}{ER}^t_i = \delta_w \cdot x^0_w \cdot \phi_{i,w} + \delta_o \cdot x^0_o \cdot \phi_{i,o} - \overline{E}^t$$

We introduce η as being the target level the economy-wide average CO_2-emissions per vkm (relative to the initial emissions level): $\eta = \dfrac{\overline{E}^t}{\left(\delta_w + \delta_o\right)}$

Then we get for the required emission reduction under a uniform standard:

$$\overset{u}{ER}{}_i^t = \delta_w \cdot (\phi_{i,w} - \eta) + \delta_o \cdot (\phi_{i,w} - \eta)$$

The optimal relation of emission reduction between each pair of manufacturers is given by:

$$\frac{ER_i^t}{ER_j^t} = \frac{\delta_o \cdot \phi_{i,o} + \delta_w \cdot \phi_{i,w} - \eta \cdot \left(\delta_o + \delta_w\right)}{\delta_o \cdot \phi_{j,o} + \delta_w \cdot \phi_{j,w} - \eta \cdot \left(\delta_o + \delta_w\right)} \forall i, j = 1, \ldots, n$$

This holds only in the case that the emission target is binding for all manufacturers. In the case that the emission target under a uniform standard is not binding for all manufacturers (and assuming manufacturers do not increase their emissions if the target is not binding for them) it holds:

$$\overset{u}{ER}{}_i^t = \begin{cases} \delta_w \cdot (\phi_{i,w} - \overset{u}{\eta}) + \delta_o \cdot (\phi_{i,w} - \overset{u}{\eta}) \Big| \delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o} > \left(\delta_w + \delta_o\right) \cdot \overset{u}{\eta} \\ 0 \Big| \delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o} \leq \left(\delta_w + \delta_o\right) \cdot \overset{u}{\eta} \end{cases}$$

In order to achieve the same economy-wide emission reduction it has to hold

$$\eta = \sum_{i=1}^{n} MS_i \cdot \begin{cases} \dfrac{\left(\delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o}\right)}{\delta_w + \delta_o} \cdot \overset{u}{\eta} \Bigg| \delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o} > \left(\delta_w + \delta_o\right) \cdot \overset{u}{\eta} \\ \dfrac{\left(\delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o}\right)}{\delta_w + \delta_o} \Bigg| \delta_w \cdot \phi_{i,w} + \delta_o \cdot \phi_{i,o} \leq \left(\delta_w + \delta_o\right) \cdot \overset{u}{\eta} \end{cases}$$

While η is the economy-wide average relative emission target as percentage of the initial emissions, $\overset{u}{\eta}$ is the relative target to be achieved by those manufacturers for whom the regulation is binding. It must always hold $\overset{u}{\eta} \geq \eta$. Some manufacturers would be allowed to emit more than the economy-wide target, because others already emit less than the target in period t=0. In the following we mostly assume that the targets are binding for all manufacturers.

Then we get for the aggregate abatement costs under a uniform standard:

$$\overset{u}{AC} = \sum_i \overset{u}{AC}_i = \sum_{i=1}^{n} \left(\left(\overset{u}{ER}{}_i^t \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot \left(\phi_{i,w}\right) + \beta_w \cdot (\delta_o)^2 \cdot \left(\phi_{i,o}\right)} \right) \cdot MS_i \right)$$

In the case that the emission standard is binding for all manufacturers this can be written as:

$$\overset{u}{AC} = \sum_{i=1}^{n} \left(\left(\delta_w \cdot (\phi_{i,w} - \eta) + \delta_o \cdot (\phi_{i,o} - \eta) \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot (\phi_{i,w}) + \beta_w \cdot (\delta_o)^2 \cdot (\phi_{i,o})} \right) \cdot MS_i \right)$$

If we compare the abatement costs under a uniform standard with the AC in the optimum, i.e.

$$\overset{opt}{AC} = \sum_{i=1}^{n} \left(\left(\overline{ER}^t \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 + \beta_w \cdot (\delta_o)^2} \right) \cdot MS_i \right) = \sum_{i=1}^{n} \left(\left(\delta_w \cdot (1-\eta) + \delta_o \cdot (1-\eta) \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 + \beta_w \cdot (\delta_o)^2} \right) \cdot MS_i \right)$$

we see that potential cost differences result solely from deviations of $\overset{u}{ER_i^t}$ from the optimal emission reduction per manufacturer: Differences in the initial values of weight and "others" have an impact on the marginal abatement costs; the higher the initial values, the lower are the MAC for a given emission reduction. However, it is important to note that the MAC for achieving a given identical emission target will be always higher for manufacturers with comparably higher initial values of weight and "others" – though their MAC for a given emission reduction are lower. Higher initial values of weight/"others" also imply higher initial emissions, which in turn means a greater emission reduction required to achieve the given target. The relative difference in the required emission reductions will always be greater than the relative difference in the initial values of weight/"others". As the disparities in the MAC are determined by the relative difference in the required emission reductions divided by the (weighted) relative differences in the initial values of weight/"others", the MAC of the manufacturers with higher initial values will be always greater. This seems reasonable from an economic viewpoint, because it would not be very intuitively that a manufacturer with higher initial emission can achieve a given emission target at lower marginal costs than a manufacturer with lower initial emissions.

In a heterogeneous market it is to be expected that such deviations exist. Achieving the emission target at least cost under a uniform standard is possible only if the manufacturers are homogeneous or – in the case of heterogeneity – if a manufacturer's higher initial weight is compensated in a cost-neutral manner by a lower initial value of "others", and vice versa.

6 Weight-Based Standards

To assess the economic implications of weight-based standards we start again with the analysis of the abatement decision of an individual manufacturer. The manufacturer faces the same AC function, but a different side condition. The decision on the allocation of abatement efforts between reducing weight and "others" now has an impact on the specific standard it has to comply with.

$$\overset{wb}{AC_i} = \min_{ER_{i,w}^t, ER_{i,o}^t} \left(\int_0^{ER_{i,w}^t} MAC_{i,w}^t + \int_0^{ER_{i,o}^t} MAC_{i,o}^t \right)$$

$$= \min_{ER_{i,w}^t, ER_{i,o}^t} \left(\int_0^{ER_{i,w}^t} \frac{2 \cdot \beta_w}{(\delta_w)^2 \cdot \phi_{i,w}} \cdot ER_{i,w}^t + \int_0^{ER_{i,o}^t} \frac{2 \cdot \beta_o}{(\delta_o)^2 \cdot \phi_{i,o}} \cdot ER_{i,o}^t \right)$$

s.t. $ER^t_{i,w} + ER^t_{i,o} = \overset{wb}{ER}{}^t_i = E^0_i - \overline{E}^t - \alpha \cdot \left(x^t_{i,w} - \sum_{j=1}^{n} \left(x^t_{j,w} \cdot MS_j \right) \right)$

A manufacturer that is subject to such a weight-based standard and that strives for cost minimization will allocate its abatement activities according to $MAC^t_{i,o} = MAC^t_{i,w} \cdot \frac{\delta_w}{\left(\delta_w - \alpha \cdot \left(1 - MS_i\right)\right)}$, which apparently is a violation of the optimum condition of equalized MAC for all abatement options. Linking the manufacturer specific emission standard to the vehicle weight leads to a distortion of the abatement decision unless i) $\alpha=0$ (but then we have a uniform standard) or ii) there exists only one manufacturer, i.e. $MS_i=1$.

If $\alpha>0$ and $MS_i<1$, then weight-based standards will result in an inefficient allocation of reduction efforts. Emission reductions achieved through weight reductions will be partially offset by a subsequent tightening of the manufacturer specific standard. Thus, weight reduction as a means of emission abatement will be used less then optimal; correspondingly, reduction of "others" will be overused. The marginal abatement costs of reducing "others" exceed those for weight reduction. The higher the value of α and the lower the market share MS_i, the higher are the disparities between the MAC and therefore the distorting effect of the weight based standard. A low market share implies that the effect of a manufacturer's weight increase on the fleet-wide average weight is very limited so that the net effect on its individual standard is relatively strong.

In case of an atomistic market, i.e. $MS_i \approx 0$, and if the slope of the limit value curve equals the physical correlation between vehicle weight and emissions, i.e. $\delta_w = \alpha$, then weight reduction will not be used at all as a means of emission reduction. In the following we mostly disregard the case of $\delta_w < \alpha \cdot \left(1 - MS_i\right)$ as it would yield absurd incentives, i.e. the regulation provides manufacturers with incentives to intentionally increase their average vehicle weight in order to boost their individual emission standard.[6]

The distorted allocation finds expression in the share of emission reductions achieved by means of reducing weight and "others". Under a weight based standard it holds:

$$ER^t_{i,w} = \overset{wb}{ER}{}^t_i \cdot \frac{\beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w} \cdot \left(\delta_w - \alpha \cdot \left(1 - MS_i\right)\right)}{\beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w} \cdot \left(\delta_w - \alpha \cdot \left(1 - MS_i\right)\right) + \delta_w \cdot \beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o}}$$

$$ER^t_{i,o} = \overset{wb}{ER}{}^t_i \cdot \frac{\delta_w \cdot \beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o}}{\beta_o \cdot \left(\delta_w\right)^2 \cdot \phi_{i,w} \cdot \left(\delta_w - \alpha \cdot \left(1 - MS_i\right)\right) + \delta_w \cdot \beta_w \cdot \left(\delta_o\right)^2 \cdot \phi_{i,o}}$$

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[6] However, there are some rather theoretical constellations conceivale where values of α, which satisfy $\delta_w < \alpha \cdot \left(1 - MS_i\right)$, are optimal for a weight-based standard.

The abatement costs of a single manufacturer subject to a weight-based standard are given by:

$$\overset{wb}{AC}_i = \left(\overset{wb}{ER_i^t}\right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot (\phi_{i,w}) + \beta_w \cdot (\delta_o)^2 \cdot (\phi_{i,o})}\right) \cdot \left(\frac{\left(\frac{\beta_o}{(\delta_o)^2} \cdot (\phi_{i,w}) + \frac{\beta_w}{(\delta_w)^2} \cdot (\phi_{i,o})\right) \cdot \left(\frac{\beta_o}{(\delta_o)^2} \cdot (\phi_{i,w}) + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}\right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot (\phi_{i,o})\right)}{\left(\frac{\beta_o}{(\delta_o)^2} \cdot (\phi_{i,w}) + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}\right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot (\phi_{i,o})\right)^2}\right)$$

Consequently, for a given, equal emission reduction, i.e. $\overset{wb}{ER_i^t} = \overset{u}{ER_i^t}$, the weight-based standard yields higher abatement costs for a single manufacturer than a uniform standard or the social optimum. This difference is determined by:

$$\frac{\overset{wb}{AC}_i}{\overset{u}{AC}_i} = \frac{\left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o}\right) \cdot \left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}\right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o}\right)}{\left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}\right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o}\right)^2}$$

The magnitude of the relative costs difference is determined by the scale of the distorting factor $\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}$ and also by the relation of the slopes of the MAC functions for reducing weight and "others". In case it holds for this relation $\frac{\frac{\beta_o}{(\delta_o)^2 \cdot \phi_{i,o}}}{\frac{\beta_w}{(\delta_w)^2 \cdot \phi_{i,w}}} = \frac{\beta_o \cdot (\delta_w)^2 \cdot \phi_{i,w}}{\beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o}} = \frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)}$, the relative cost difference reaches its maximum.

However, for a reasonable comparison of weight-based and uniform standards, cost differences for a given emission reduction per manufacturer are of minor importance. In fact, it is the main argument in favor of weight-based standards to differentiate the manufacturer specific emission reduction targets with view to their individual marginal abatement costs. Hence, we have to suspend this assumption for a meaningful analysis of both approaches. Thus, we first have to look at the impact of using weight as reference parameter on the allocation of emission reductions across manufacturers before we can draw conclusions on the economic implications of choosing either regulatory approach.

Using the equations for $ER_{i,w}^t$ and $ER_{i,o}^t$ as well as the side condition

$$\overset{wb}{ER}_i^t = \delta_o \cdot \phi_{i,o} + \delta_w \cdot \phi_{i,w} - \eta \cdot (\delta_o + \delta_w) - \alpha \cdot \left(x_{i,w}^t - \sum_{j=1}^{n} x_{j,w}^t \right)$$

$$= \delta_o \cdot \phi_{i,o} + \delta_w \cdot \phi_{i,w} - \eta \cdot (\delta_o + \delta_w) - \alpha \cdot \left(\left(\phi_{i,w} - \frac{\overset{wb}{ER}_{i,w}^t}{\delta_w} \right) - \left(1 - \sum_{j=1}^{n} \left(\frac{\overset{wb}{ER}_{j,w}^t}{\delta_w} \cdot MS_j \right) \right) \right)$$

we can determine the emission reduction conducted by each manufacturer:

$$\overset{wb}{ER}_i^t = \frac{\delta_o \cdot \phi_{i,o} + \delta_w \cdot \phi_{i,w} - \eta \cdot (\delta_o + \delta_w) + \alpha \cdot \left(1 - \phi_{i,w} - \left(\sum_{j \neq i} \frac{\overset{wb}{ER}_j^t \cdot \beta_o \cdot (\delta_w - \alpha \cdot (1 - MS_j)) \cdot \phi_{j,w}}{\beta_o \cdot (\delta_w - \alpha \cdot (1 - MS_j)) \cdot \delta_w \cdot \phi_{j,w} + \left(\beta_w \cdot (\delta_o)^2 \cdot \phi_{j,o} \right)} \cdot MS_j \right) \right)}{\left(1 - \frac{\beta_o \cdot (\delta_w - \alpha \cdot (1 - MS_i)) \cdot \phi_{i,w}}{\beta_o \cdot (\delta_w - \alpha \cdot (1 - MS_i)) \cdot \delta_w \cdot \phi_{i,w} + \left(\beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o} \right)} \cdot (1 - MS_i) \cdot \alpha \right)}$$

$\forall i, j = 1, \ldots, n$

According to the interdependence of the emission reduction decisions of all manufacturers - via the influence of the economy-wide average weight on the manufacturer specific emission targets – $\overset{wb}{ER}_i^t$ can be determined only simultaneously as a Nash-equilibrium for all manufacturers.

After determining the emission reduction of each manufacturer we can calculate the aggregate economy-wide abatement costs under a weight-based standard as

$$\overset{wb}{AC} = \sum_{i=1}^{n} \left(\left(\overset{wb}{ER}_i^t \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot \phi_{i,w} + \beta_w \cdot (\delta_o)^2 \cdot \phi_{i,o}} \right) \cdot \left(\frac{\left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o} \right) \cdot \left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)} \right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o} \right)}{\left(\frac{\beta_o}{(\delta_o)^2} \cdot \phi_{i,w} + \left(\frac{\delta_w}{\delta_w - \alpha \cdot (1 - MS_i)} \right)^2 \cdot \frac{\beta_w}{(\delta_w)^2} \cdot \phi_{i,o} \right)^2} \right) \cdot MS_i \right)$$

For each set of parameters $\beta_w, \beta_o, \delta_w, \delta_o, \phi_{i,w}, \phi_{i,o}, MS_i, \eta$ it is possible to determine the value of α that minimizes the aggregate abatement costs.

7 Uniform vs. Weight-based Standards Compared

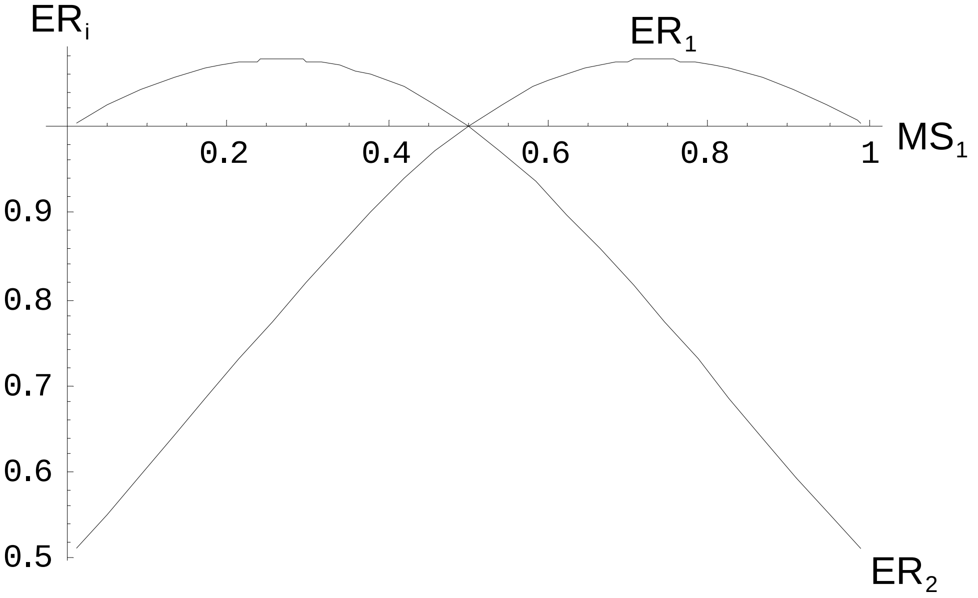
In this chapter we will analyze the implications of the parameters $\beta_w, \beta_o, \delta_w, \delta_o, \phi_{i,w}, \phi_{i,o}, MS_i, \eta$ for the relative favorability of both regulatory approaches, i.e. either uniform or weight-based standards. First, we will briefly assess the – not very realistic – case of homogeneous manufacturers; the results are relatively trivial and do not justify greater attention. Then we will regard the more interesting case of heterogeneous manufacturers, in which either of the both approaches – uniform or weight-based standards – can yield better results.

7.1 Homogeneous Manufacturers

When the manufacturers are homogeneous, i.e. they have i) identical initial values for weight and "others", ii) identical reduction cost functions, iii) identical emission functions, and iv) identical market shares, then the results for a single manufacturer can be transferred to the entire economy. The relative difference in the aggregate abatement costs as well as the absolute difference in the abatement costs (per vehicle) will be the same as in the case of a single manufacturer subject to the same emission reduction requirement; it does not make a difference whether we regard one or more equal manufacturers.

All being equal except the market share, then the market shares determine the welfare loss of a weight-based standard compared to a uniform standard. The higher the market shares, the smaller is the welfare loss. The lower the market share of a manufacturer, the more unattractive is weight reduction as a means of emission abatement as the manufacturer does not have a great impact on the average weight of the entire fleet. Thus, the manufacturer will reduce the weight of its vehicles to a smaller extent than those manufacturers with higher market shares. In the equilibrium, manufacturers with low market shares will have emissions above the average emission per vehicle, manufacturers with high market shares will emit below the average.

The following plot shows the emission reductions of two manufacturers with equal characteristics, except the market shares: Starting with a marginal market share of almost 0, the manufacturer realizes a significantly smaller emissions reduction. With both manufacturers having a market share of 0.5 the emission reduction graphs intersect. With a market share greater than 0.5 the emission reductions carried out are above the average.



7.2 Heterogeneous Manufacturers

There are generally two factors with oppositional impacts that affect the relative favorability of either uniform or weight-based standards. On the one hand, differences in the initial emissions and therefore in the required emission reduction cause excessive abatement costs compared to the social optimum; these can be attenuated by means of introducing a reference parameter – here weight – that determines manufacturer specific reduction targets taking account of different initial positions. On the other hand, the use of such a reference parameter distorts the choice between different abatement options, thereby increasing a manufacturer's costs for achieving a certain emission reduction. Thus, the relative impact of these factors determines, which regulatory approaches facilitates the realization of a given emission reduction target at lower costs. If the first factor dominates, then a weight-based standard will yield the better results; uniform standards are preferable if the distorting effect has greater weight. In the following we will analyze the influence of the parameters $\beta_w, \beta_o, \delta_w, \delta_o, \phi_{i,w}, \phi_{i,o}, MS_i, \eta$ on the choice of the standard. We will assume that the regulator is capable to estimate the optimal α for any set of parameters;[7] however, as this assumption is very questionable we will also mention the sensitivity of the results to a suboptimal choice of α.

It has to be noted that the following considerations about the impact of $\beta_w, \beta_o, \delta_w, \delta_o, \phi_{i,w}, \phi_{i,o}, MS_i, \eta$ on the relative efficiency of weight-based versus uniform standards are undertaken under ceteris paribus assumptions. Where necessary case differentiations are made; yet, there remain various complex interdependencies, which cannot be described in all details.

7.2.1 Market Concentration

Ceteris paribus, it holds that the higher the market concentration, the relatively better perform weight-based standards. Manufacturers with low market shares have only small impacts on the average vehicle weight of the economy-wide fleet. In consequence, the net tightening effect of weight reductions on its specific standard is relatively strong; the distortion of the allocation decision between abatement by means of weight reduction or reduction of "others" is stronger than for manufacturers with greater market shares. The abatement cost savings achievable with a weight-based regulation – using an optimal α – are smaller in markets with low market concentration rates than in more concentrated markets. The value of α, which minimizes the abatement cost under a weight-based standard, increases with the market concentration, and vice versa: Due to the distortion amplified by low market shares, smaller values of α are required to offset this effect.

7.2.2 Emission Reduction Target

The emission level (in terms of percentage of initial emissions) aimed at by the regulator has a strong impact on the abatement cost relations between the social optimum, weight-based standards, and uniform standards. In case of a minor required emission reduction the cost differences are greatest. A market with heterogeneous manufacturers subject to uniform standard implies significant disparities in the emission reductions to be achieved by each manufacturer; the smaller the overall reduction target, the greater are the disparities of individual targets. In the optimum, however, all manufacturers have to contribute to the aggregate emission reduction target; the differentiation of individual targets should take place only to the extent of differences in the initial values of weight and "others". Thus the relative cost difference between the optimum and a uniform standard increases with the emission target, i.e. the less ambitious the target, the greater is the cost difference.

In the first instance, the same problem applies to weight-based standards as they are uniform standards with an adjustment clause based on the average weight of a manufacturer's fleet. This weight-based term of the limit value curve is designed to attenuate the problems of uniform standards. As mentioned above the disparities in the required emission reduction are

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[7] Under this assumption the abatement costs of a weight-based standard will never exceed those of a uniform standard, because α can be set to zero so that the weight-based standard will achieve at least the result of the uniform standard.

the greatest if η is close to 1; consequently, the optimal value of α to compensate for these disparities has to be higher, the higher η. As a high α implies a relatively strong distortionary effect, it also holds for the weight-based standard that its relative additional costs compared to the optimum increase with η.

Nevertheless, the weight-component in the calculation formula of the manufacturer specific standards brings about that the gap in costs is mitigated; the distortion of the allocation between reductions of weight or “others” is overcompensated by the positive effect mitigating the required emission reductions. With more ambitious emission targets the differences in the required emission reductions across manufacturers diminish so that the correction by means of the weight-based adjustment becomes less important. Hence, the abatement cost difference between weight-based and uniform standards also diminishes with decreasing η, i.e. more ambitious emission targets.

When it comes to the absolute cost difference the nexus is ambiguous. Starting at $\eta=1$ the absolute difference at first rises with decreasing η as the general absolute cost levels also increases; however, with further decreasing η there comes the point where the declining relative cost difference outweighs the rising absolute cost level and the abatement cost gap begins to shrink.

7.2.3 Costs of the Reduction Options

The relative costs of the both considered emission abatement options, i.e. the costs for weight reduction β_w and the costs for reduction of others β_o, have an impact on the relative favorability of weight-based standards. The parameters β_w and β_o do not directly represent the abatement costs in terms of costs per abated emission unit, but the costs for reducing the weight or “others”; however, they are linearly correlated with the marginal abatement costs of the respective abatement option.

We find that the more expensive weight reduction relative to reduction of “others”, i.e. the greater β_w/β_o, the better performs the weight-based standard compared to the uniform standard. We know that a weight-based standard distorts the decision between using weight reduction or reduction of “others” as means of emission abatement. If the relation β_w/β_o is great, then weight reduction has only little importance as means of abatement so that the perceived increase in costs due to the weight-based standard has only small effects; weight reduction is hardly used anyway. On the other hand, if the relation β_w/β_o is relatively small, then weight reduction is the dominating option to reduce emissions; its cost increase perceived by the manufacturers (according to the tightening of the standard) has a greater impact.

For the relative abatement cost difference this relation is stable and monotone. This does not hold for the absolute abatement cost difference, at least if we suspend the assumption that the regulator always finds the optimal value for α. Let us regard the situation where a weight-based standard is in place, which exceeds the costs of the uniform standard, and the regulator does not set $\alpha=0$. Then an increase of β_w improves, on the one hand, the relative position of the weight-based standard, but it does also, on the other hand, raise the general cost level. In this situation the absolute cost difference could increase with increasing β_w/β_o, although the relative difference diminishes. However, assuming a perfectly informed regulator this situation will not occur, because the costs of the weight-based standard cannot exceeds those of the uniform standard as the regulator can always switch to a uniform standard by setting $\alpha=0$.

7.2.4 The Contribution to Emissions of Weight and “Others”

The parameters δ_w and δ_o determine the contribution of weight and “others” respectively to the initial emissions, and have an important impact on the marginal abatement costs of both weight reduction and reduction of “others”. The relation δ_w/δ_o determines the share of weight and “others” induced emissions in period t=0. If δ_w exceeds δ_o, then weight is the dominating driver of emissions; on the other hand, this regularly goes along with a relatively high importance as means of emission reduction. This becomes apparent when we recall that $(\delta_w)^2$ is in the denominator of the MAC function.

The effect of the relation δ_w/δ_o is not unambiguous so that we have to make a case differentiation. In case there is a positive empirical correlation between the initial values of weight and “others”, then the weight-based standard performs the better, the smaller δ_w/δ_o. A small value of δ_w implies that weight reduction is of minor importance for reaching the emission target; thus, the distortion in form of a perceived cost increase of weight reduction has only a relatively small impact on the allocation of abatement efforts. The positive correlation between the initial values of weight and “other” ensures that the weight-based component in the limit value curve also captures disparities in the initial values of “others”. Consequently, the weight-component is relatively effective in capturing differences in the required emission reductions, but the efficiency losses due to a distortion of the abatement decision are limited.

In case of a negative correlation we observe contrary effects. In that case, the manufacturers’ weight is not necessarily an indicator for their overall emissions. Higher emissions due to high weight may be offset or even be overcompensated by lower values of “others”. Particularly in the latter case it may happen that less ambitious targets are granted to manufacturers with relatively low emissions, which could lead to excessive abatement costs. Such effects were due to the fact that the emission target is linked only to the initial weight, which is an unreliable indicator for the overall emissions. This effect is particularly relevant if δ_w/δ_o is small, because vehicle characteristic other than weight mainly determine the emissions. On the other hand, if weight is the by far dominating determinant of the vehicles emissions, i.e. δ_w/δ_o is very high, then the negative correlation is of less importance. The emissions are primarily caused through the weight so that a weight component in the standard calculation formula can still bring about abatement cost savings.

7.2.5 Heterogeneity and Correlation of Parameters

As already shown, the variance of the initial emissions and thereby the required emission reductions under a uniform standard are of crucial importance for the efficiency of this regulatory approach. A high variance of the initial emissions implies significant deviations of the costs of the uniform standard from the social optimum. The introduction of variable manufacturer specific standards based on the vehicle weight allows partially compensating for that. Thus, weight-based standards regularly perform – compared to uniform standards – the better, the higher the variance of the initial emissions. Compared to the social optimum, weight-based standards also perform worse if there is a great variance of the initial emissions. It generally holds that the greater the variance of the initial emissions, the greater is the optimal value of α, and consequently the distortionary effect.

Still, we have to make a case differentiation again. The variance of the initial emissions is determined by the variance of the weight and of “others” (weighted with δ_w and δ_o respectively):

$$Var(E_i^0) = Var(\delta_w \cdot \phi_{i,w}) + Var(\delta_o \cdot \phi_{i,o}) + Cov(\delta_w \cdot \phi_{i,w}, \delta_o \cdot \phi_{i,o})$$
$$= (\delta_w)^2 \cdot Var(\phi_{i,w}) + (\delta_o)^2 \cdot Var(\phi_{i,o}) + \delta_w \cdot \delta_o \cdot Cov(\phi_{i,w}, \phi_{i,o})$$

If weight and “others” are (empirically) positively correlated, higher variance of either weight or “others” (or both at the same time) will necessarily lead to a higher variance of the initial emissions, thereby favoring weight-based standards.

If we have a significant negative correlation, then an increasing variance of “others” will support a uniform standard. An increased variance of “others” may decrease the variance of the required emission reductions through a parallel increase (in absolute terms) of the (negative) covariance. In that case the change in the covariance overcompensates the effect of the variance increase of “others”. As the initial emissions converge, the absolute abatement costs for complying with the uniform standard are also expected to decrease.

Moreover, with a negative correlation an increasing variance of “others” supports the introduction of a uniform standard, even if this implies an increase of the variance of the initial emissions.[8] In this case it holds – due to the negative correlation – that the emissions of a manufacturer are the lower, the higher the initial weight. It is apparent that a weight-based regulation that grants higher emission targets for manufacturers producing heavier vehicles becomes less attractive.[9] Although, the increasing variance of “others” will affect the efficiency of both regulatory approaches negatively, the efficiency loss is greater for the weight-based standard. On the other hand, increasing variance of the reference parameter, i.e. weight, always strengthen the position of weight-based standards, also under a negative correlation.

As a positive or at least no correlation is certainly more likely than a negative correlation of the emission determining vehicle attributes, we can take that under most circumstances high heterogeneity of the manufacturers in the market to regulate is rather in support of weight-based standards.

8 Standards Based on Past Weight

An alternative approach to cope with the main problem of the above analyzed weight-based standards – the distortion of the abatement decision – is a standard design that defines the manufacturer specific emission limit based on the past instead of current weight.

Each manufacturer would face then the following side condition, which is not affected by its current decisions:

$$ER^t_{i,w} + ER^t_{i,o} = \overset{pwb}{ER^t_i} = E^0_i - \bar{E}^t + \alpha \cdot \left(\phi^t_{i,w} - \sum_{j=1}^{n} \left(\phi^t_{j,w} \cdot MS_j \right) \right) = E^0_i - \bar{E}^t + \alpha \cdot \left(\phi^t_{i,w} - 1 \right)$$

The aggregate abatement costs to the entire economy are then:

$$\overset{pwb}{AC} = \sum_{i=1}^{n} \left(\left(\overset{pwb}{ER^t_i} \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot (\phi_{i,w}) + \beta_w \cdot (\delta_o)^2 \cdot (\phi_{i,o})} \right) \cdot MS_i \right)$$

$$= \sum_{i=1}^{n} \left(\left(\delta_w \cdot (\phi_{i,w} - \eta) + \alpha \cdot \left(\phi^t_{i,w} - 1 \right) + \delta_o \cdot (\phi_{i,o} - \eta) \right)^2 \cdot \left(\frac{\beta_o \cdot \beta_w}{\beta_o \cdot (\delta_w)^2 \cdot (\phi_{i,w}) + \beta_w \cdot (\delta_o)^2 \cdot (\phi_{i,o})} \right) \cdot MS_i \right)$$

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[8] Also with a negative correlation, increases in the variance of one parameter can still lead to increasing variances of overall initial emissions, if the variance of the parameter, which is already the dominating determinant of the overall emissions, is further increasing.

[9] We abstract here from the opportunity of introducing a negative α. If we allow for negative values of α, it generally holds that the weight-based standards performs the better (compared to uniform standards), the higher the empirical correlation of weight and „others“.

Apparently, the weight component α has an effect on the manufacturer specific standard only, but leaves the decision between the different abatement options unaffected. Each manufacturer will allocate its abatement efforts in a manner that equalizes its MAC for reducing weight and for reducing "others". However, differences in the MAC between different manufacturers will normally remain, even with an optimally chosen α. As the emission target is fixed a priori, achievement of the fleet-wide target is assured with this approach. Since the assignment of the manufacturer specific standards is based on past values of a performance variable it could be described as a combination of grandfathering and benchmarking.

In the model setting used here standards based on past weight always perform better than (or at least equal to) standards based on current weight if both approaches use their respective optimal α. They use the same mechanism to account for differences in the initial emission and thereby MAC differences across manufacturers, but they dispense with the distortionary effect that reduces the efficiency of the latter approach. For a given market structure, the optimal α is always greater or equal than the optimal α under standards based on current vehicle weight. Standards based on past weight dominate uniform standards in most instances, too. Only in the case of a strong negative correlation of the initial values of weight and "others" α has to be set to equal and they yield the same results as uniform standards. Maybe even more important is the fact that – suspending the assumption that the regulator chooses the optimal α – the potential excess burden of a suboptimally chosen α are significantly lower than with the standard based on current weight due to the absence of the distortion.

However, there are situations conceivable – at least in theory, where standards based on current weight perform better than those based on past weight. For instance, there may be a situation where a "too high" α reduces the required emission reduction under a standard based on past weight too much.[10] Thus, the manufacturer with higher initial emissions (and higher initial weight) abates less than optimal; the manufacturer with lower initial emissions abates too much (in the simple case of only two manufacturers). With a standard based on current weight this effect could be weaker as the manufacturer with the higher initial weight will – as long as α is relatively small – mainly reduce its weight and thereby also reduce the weight disparities. Thus, its required emission reduction decreases less than with the standard based on past weight; the required emission reductions are closer to the optimal emission reductions. In such a situation it could happen that the above described effect, i.e. the required emission reductions are closer to the optimum, overcompensates the adverse distortionary effect of the standard based on current weight. It is important to note that we suspended for this consideration the assumption that the regulator has chosen optimal values of α; instead both approaches are assumed to deploy the same α.

An example for such a case is given in the following graphs.[11] The left graph shows the relation $AC^{pastweight}/AC^{currentweight}$ depending on α, the right graph shows the emission reductions of both manufacturers for both regulatory approaches depending on α. The linear graphs are the required emission reduction under a standard based on past weight. We can see that for certain values of α the standard based on current weight performs better than the standard based on past weight. As described before this due to the fact that the emission reductions conducted by each manufacturer are closer to the optimum: The manufacturer with the higher initial emissions reduces its emissions more under the standard based on current weight, which increases the relative efficiency of the standard.

For small values of α, the standard based on past weight performs better, because the emission reductions of the manufacturer with the high initial weight are still lower than optimal (see chapter on uniform standards), in particular under the standard based on current weight. For

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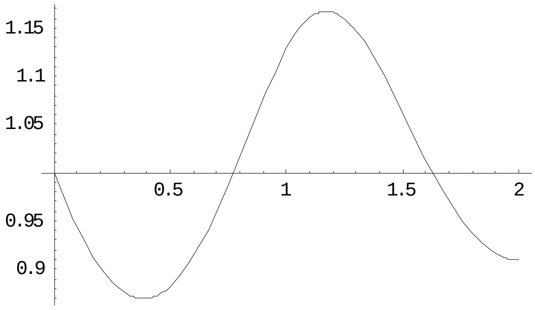
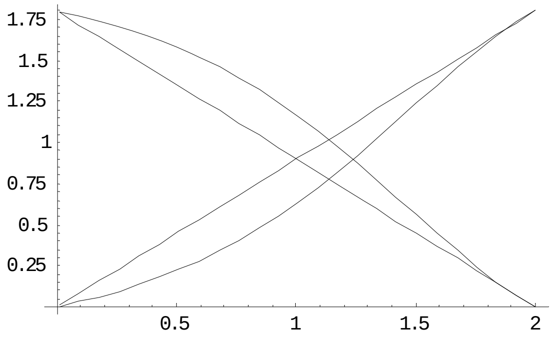
[10] This may happen if there is no or negative correlation between weight and „others".

[11] Both manufacturers are identical in all their characteristics, except for their initial weights.

very high values of α, the standard based on past weight performs better again, because the distortionary effect prevails. It should be noted once again that the standard based on past weight will always perform better if the regulatory authorities are capable of determining the optimal value of α; in the example given here the optimal α will be in the range before the graph intersects with the abscissa for the first time.





Further alternative standard designs are currently under examination and will be included in the conference presentation if the paper is accepted for presentation.

9 Policy Implications

As the research project is not finished yet, there are only some preliminary policy implications so far. An evaluation of the different potential design options of vehicle emission standards will be conducted soon based on further simulation runs, actual market structures, and technological cost data from the EU and the US (Volpe model of the NHTSA).

- Fuel economy standards/vehicle emission standards are a widely used instrument of climate policy. So far, uniform and performance based standards without trading mechanisms prevail. However, a theoretical analysis of these design alternatives is missing as yet. We use a straightforward microeconomic model to assess the relative favorability of reference parameter based vehicle emissions standards – in particular weight-based standards – compared to uniform standards.
- None of the analyzed approaches shows a general dominance over the others.
- Crucial for the relative favourability is the prevailing market structure (market concentration rates, cost structures, and particularly the heterogeneity of the vehicle manufacturers). Thus, an individual assessment for each market is indispensable.
- If the regulator has sufficiently good information, a weight-based standard will always yield lower (or at least equal) aggregate abatement costs than a uniform standard; standards based on past values of vehicle weight will perform better than standards based on current weight.
- Particularly in the diversified, heterogeneous European auto market a uniform standard for all vehicles would imply excessive reduction costs and is politically not feasible due to its distributive effects.
- The EU (linear weight-based standards) and the US (probably S-shaped footprint-based standards) have made different choices with regard to the used reference parameter. Our theoretical results suggest that using vehicle weight as reference parameter will lead to greater distortions in the allocation decision between different abatement options than the

footprint approach. Adjusting the reference parameter (e.g. weight reduction, downsizing) in order to abate CO_2-emissions is devaluated by linking the specific emission target to the level of the reference parameter. This problem seems to be of greater importance in the case of weight based standards; a footprint-based regulation is less vulnerable to adjustments in the design of the vehicles in order to attenuate the required emission reduction – due to technical reasons and for lack of consumer acceptance.

- We conclude that the most efficient implementation of vehicle emission standards is a scheme of tradable emission (reduction) credits. In order to fully exploit its efficiency properties the initial credit endowments have to be independent of any design characteristics of the respective vehicles. The distributional impacts of such a scheme – across manufacturers as well as across regions – are crucial for its political viability; a potential approach to cope with undesired distributional effects is to grant manufacturers of relatively emission-intensive vehicles initial emission endowments based on past average CO_2 emissions of their fleet, which should converge over time.

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